Recent results on central exclusive production with the STAR experiment at RHIC*

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We report on the measurement of the central exclusive production process $pp \rightarrow ph^+h^-p$ in proton-proton collisions with the STAR detector at RHIC at two different center-of-mass energies $\sqrt{\mathrm{s}} = 200$ GeV and $\sqrt{\mathrm{s}} = 510$ GeV. At these energies, the process is dominated by a double Pomeron exchange mechanism. The charged particle pairs were constructed by combining oppositely charged tracks within the central detectors of STAR, the Time Projection Chamber and the Time of Flight. The pairs were identified using the ionization energy loss and the time of flight method. Diffractively scattered protons, which remain intact inside the RHIC beam pipe after the collision, were measured in the Roman Pots system allowing full control of the interaction's kinematics and verification of its exclusivity. In these proceedings, we present differential cross sections for centrally produced $\pi^+\pi^-$, K^+K^-, and $p\bar{p}$ pairs measured within the STAR acceptance at $\sqrt{\mathrm{s}} = 200$ GeV together with the preliminary results on the measurement of the same physics process at the higher center-of-mass energy, $\sqrt{\mathrm{s}} = 510$ GeV.

1. Introduction

Measurement of Central Exclusive Production (CEP) [1], a procees through the Double Pomeron Exchange (DIPE), allows us to study the strong interaction described by the quantum chromodynamics. It is also suitable to study hadronic production of glueballs [2], hypothetical bound states consisting of only gluons. CEP through DIPE is a process, where each colliding proton "emits" a Pomeron [1]. The Pomerons "fuse" and produce a neutral

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central system with quantum numbers of vacuum. The central system is well separated from outgoing intact protons by large rapidity gaps.

Despite the fact that CEP is topologically very simple, it is theoretically very complex and rich phenomena. The CEP includes both resonance and continuum productions. Hence, significant interference effects between resonance and continuum production are present. Furthermore, there may be significant rescattering (absorption) effects via additional interaction between the protons and/or hadron and proton [4]. A generic diagram of CEP with resonance and continuum production is shown in Fig. 1.

The data from the Solenoidal Tracker at RHIC [5] (STAR) experiment at the Relativistic Heavy Ion Collider [3] (RHIC), gives a unique opportunity to perform such studies since the DIPE is expected to be dominant CEP mechanism at RHIC energies [4]. This was confirmed by the most recent results of the CEP in proton-proton collisions at $\sqrt{s} = 200$ GeV [4]. The detection of the forward-scattered protons with the measurement of the central system allows full control of the interaction's kinematics and verification of its exclusivity.

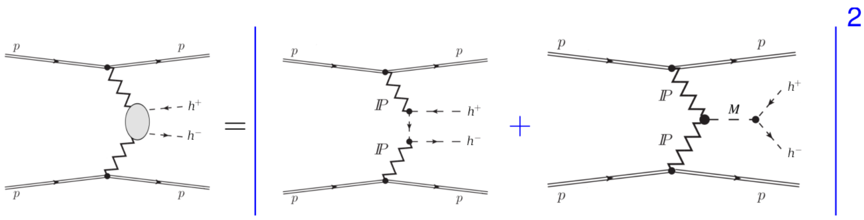

Fig. 1. A generic diagram of central exclusive production of two hadron as combination of continuum and resonance production.

2. Experimental setup

The STAR is a multi-purpose detector consisting of many sub-detectors, allowing measurement and identification of particles. In the Time Projection Chamber [6] (TPC), charged particles are tracked and their energy loss as a function of their momenta is measured in pseudorapidity range of $|\eta| < 1$ and full azimuthal angle. In combination with measuring the time-of-flight information in the Time Of Flight [7] (TOF) system, the STAR detector enables precise particle identification. Forward rapidity Beam-Beam Counters [8] (BBC), covering $2.1 < |\eta| < 5.0$, are used to ensure rapidity gaps. In addition, the STAR experiment has silicon strip detectors installed in Roman Pots [9] at 15.8 and 17.6 meters on both sides of the interaction point to measure protons from the CEP process. In each Roman Pot, a package of four silicon strip detectors and a scintillation trigger counter is installed giving spatial resolution of 30 μm and active area of 79×49 mm^2. The capability of measuring forward-scattered protons' transverse momenta is crucial to verify the exclusivity.

3. Data sample and event selection

In 2015 and 2017, the STAR experiment collected proton-proton collision data at $\sqrt{s}$ = 200 and 510 GeV, respectively. About 622 (560) million CEP event candidates were triggered in 2017 (2015). The next paragraphs describe the selection criteria used to select a sample of CEP events at $\sqrt{s}$ = 510 GeV. The selection criteria used at $\sqrt{s}$ = 200 GeV are similar, their detailed description can be found here [4].

The CEP events were triggered by requiring signals in at least one Roman Pot station in lower or upper branch on each side of the interaction point and requiring lack of signals in the other branches to reduce pile-up events, or events involving proton dissociation. In the TOF, $2-10$ hits were required to ensure at least two in-time tracks in the TPC. Moreover, a veto on signals in both the BBC and the Zero Degree Calorimeter detectors was imposed to ensure the rapidity gaps characteristic to CEP events.

In the offline analysis, only events with exactly one forward-scattered proton, measured in Roman Pots, on each side of the interaction point were selected. This was achieved by requiring to have all eight silicon planes used in the proton reconstruction and to have transverse momenta of the scattered protons inside a fiducial region, as listed in the legend of Fig. 2 (right), to ensure high geometrical acceptance and good track quality.

Next, the information of the central system was checked. Only events with exactly two opposite-charged TPC tracks matched with two TOF hits, originating from the same vertex, were selected. To ensure high geometrical acceptance for the central tracks in the entire fiducial phase space, further criteria were applied: a cut on the $z-$position of the vertex ($|z$-position of vertex$| < 80$ cm) and a cut on pseudorapidity of central tracks ($|\eta| < 0.7$). In addition, tracks reconstructed in the TPC had to satisfy track quality cuts – number of hits used in track reconstruction (> 25) and number of hits used for determining the ionization energy loss (> 15).

Then, the cut on the missing transvere momentum ($p_{\mathsf{T}}^{\mathsf{miss}} < 100$ MeV) was used to ensure exclusivity of the event. The $p_{\mathsf{T}}^{\mathsf{miss}}$ is defined as the absolute value of sum of the transverse momenta of all measured particles. Due to the conservation of the momentum, the $p_{\mathsf{T}}^{\mathsf{miss}}$ should be equal to zero for the CEP processes.

Finally, the particle identification was done based on combined information from the TPC, the ionization energy loss of the particle, and from TOF (m^2_{TOF}) [4], where the m^2_{TOF} is the squared invariant mass of a particle type

(π, K, and p). After applying all the selection criteria mentioned above, 62077 $\pi^+\pi^-$, 1697 K^+K^-, and 125 $p\bar{p}$ CEP event candidates were selected.

4. Results

In Fig. 2 (left), the differential cross-section for CEP of $\pi^+\pi^-$ at $\sqrt{s} =$ 200 GeV [4] as a function of the invariant mass of the pair is presented with Monte Carlo model predictions from Dime [11], GenEx [12] and the MBR model [13]. Since these models account for continuum production only, they are not expected to fully describe the data. Figure 2 (right) shows the invariant mass distribution of selected $\pi^+\pi^-$ pairs at $\sqrt{s} = 510$ GeV with GRANIITTI [10] prediction. It calculates invariant mass spectra assuming both continuum and resonance contributions. Hence, it takes into account significant interference effects. In addition, significant rescattering (absorption) effects via additional interaction between the protons and/or hadron-proton are also embedded. The new tune GRANIITTI v. 1.080 includes CEP resonance couplings also tuned to the STAR CEP results at $\sqrt{s} =$ 200 GeV [4]. The following resonances were included in the GRANIITTI calculation: $f_0(500)$, $\rho(770)$, $f_0(980)$, $\phi(1020)$, $f_2(1270)$, $f_0(1500)$, $f_2(1525)$, and $f_0(1710)$. The results at $\sqrt{s} = 510$ GeV were corrected for particle reconstraction efficiency in the TPC and TOF. The correction is called "acceptance corrected" as the full efficinecy coorections are still under study. The results were normalized such that area under the distribution is equal to one. The invariant mass distribution of $\pi^+\pi^-$ pairs shows expected features: a drop at about $m(\pi^+\pi^-) = 1$ GeV, possibly due to the quantum mechanical negative interference of $f_0(980)$ with the continuum contribution, and a peak consistent with the $f_2(1270)$. Shown error bars represent the statistical uncertainties only and natural units are used.

Figure 3 shows the invariant mass distribution of $\pi^+\pi^-$ pairs at $\sqrt{s} =$ 510 GeV differentiated in two regions of $\Delta\varphi$, where different Pomeron dynamics is expected. The $\Delta\varphi$ is the difference of azimuthal angles between the forward protons. A suppression of $f_2(1270)$ and an enhancement at low invariant mass in $\Delta\varphi < 90°$ are seen. Figure 4 illustrates invariant mass distributions of selected K^+K^- and $p\bar{p}$ pairs measured within the STAR acceptance. The invariant mass of K^+K^- pairs shows a peak at about $m(K^+K^-) = 1.5$ GeV, possible $f_2(1525)$, and a strong enhancement at low invariant mass, possible $f_0(980)$ or $\phi(1020)$. The invariant mass distribution of $p\bar{p}$ pairs has low statistics and does not show any resonances. In general, GRANIITTI can describe shapes of all presented distributions at $\sqrt{s} = 510$ GeV.

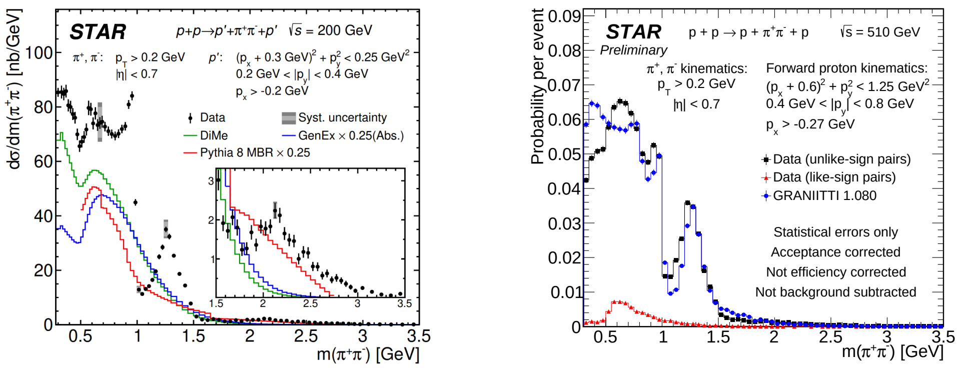

Fig. 2. Left: Differential cross-section as a function of invariant mass of $\pi^+\pi^-$ pairs at $\sqrt{s} = 200$ GeV. Right: The acceptance corrected invariant mass spectrum of exclusively produced $\pi^+\pi^-$ pairs at $\sqrt{s} = 510$ GeV.

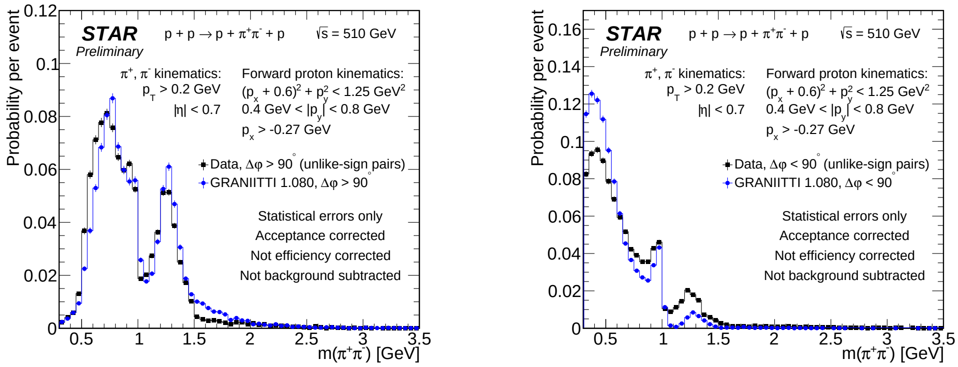

Fig. 3. Acceptance corrected invariant mass spectra of exclusively produced $\pi^+\pi^-$ pairs in two regions of the difference of azimuthal angles of the forward-scattered protons: $\Delta\varphi > 90°$ (left) and $\Delta\varphi < 90°$ (right). Error bars represent the statistical uncertainties.

5. Summary

Recent results on the CEP of $\pi^+\pi^-$, K^+K^-, and $p\bar{p}$ pairs measured with the STAR experiment in proton-proton collision at $\sqrt{s} = 200$ and 510 GeV have been presented. The presented results confirm features seen in previous experiments with some new features like the peak at about $m(K^+K^-) = 1$ GeV in the distribution of K^+K^- pairs at $\sqrt{s} = 510$ GeV are obserbed. The new Monte Carlo event generator, GRANIITTI, is able to describe the shape of the presented data suggesting significant role of resonance production in the CEP process.

Acknowledgments

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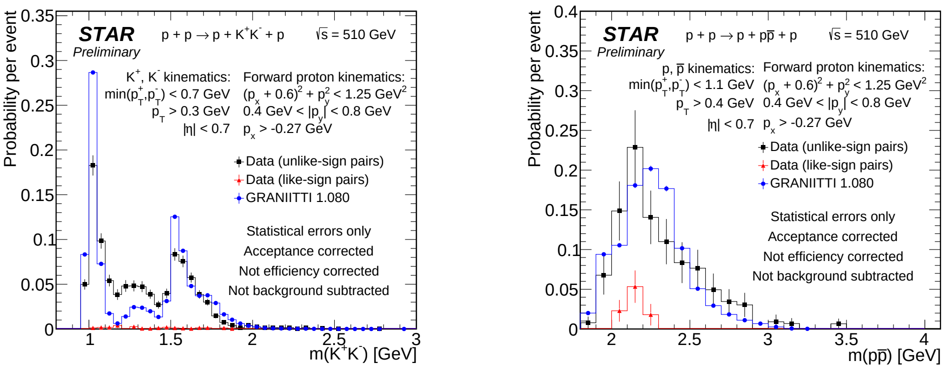

Fig. 4. Acceptance corrected invariant mass spectra of exclusively produced K^+K^- (left) and $p\bar{p}$ (right) pairs at $\sqrt{s} = 510$ GeV. Error bars represent the statistical uncertainties.

REFERENCES

[1] M. G. Albrow, T.D. Coughlin and J.R. Forshaw, *Prog. Part. Nucl. Phys.* **65**, 149 (2010).

[2] K. Ishikawa, G. Schierholz and M. Teper, *Z. Phys. C* **19**, 327 (1983).

[3] H. Hahn *et al.*, *Nucl. Instrum. Meth.* **499**, 245 (2003).

[4] STAR Collab., (J. Adam *et al.*), *JHEP* **07**, 178 (2020).

[5] STAR Collab., (K.H. Ackermann *et al.*), *Nucl. Instrum. Meth.* **499**, 624 (2003).

[6] M. Anderson *et al.*, *Nucl. Instrum. Meth.* **499**, 659 (2003).

[7] STAR Collab., (J. Wu *et al.*), *J. Phys. G* **34**, 729 (2007).

[8] STAR Collab., (C. A. Whitten *et al.*), *AIP Conf. Proc.* **980**, 1 (2008).

[9] S. Bultmann *et al.*, *Nucl. Instrum. Meth.* **535**, 415 (2004).

[10] M. Mieskolainen, *arXiv*:1910.06300

[11] L. A. Harland-Lang *et al.*, *Eur. Phys. J. C* **74**, 2848 (2014)

[12] R. A. Kycia *et al.*, *Commun. Comput. Phys.* **24**, 860 (2018)

[13] R. Ciesielski and K. Goulianos, *PoS* **174**, 301 (2013)